

## PROJECT SUMMARIES

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### **TOTAL SHIP SYSTEMS ENGINEERING CVNX AIRCRAFT CARRIER DESIGN EXPLORATION AND SUPPORT**

**Charles N. Calvano, Associate Professor**

**Department of Mechanical Engineering**

**Robert C. Harney, Associate Professor**

**Department of Physics**

**Sponsor: CVNX Program Office**

**OBJECTIVE:** To explore innovative design approaches for a future U.S. Navy aircraft carrier and contribute to discussions of CVNX developments by participation in and support of the CVNX Analysis of Alternatives (AOA) process. Introduce officer students to the unique design challenges associated with aircraft carriers.

**SUMMARY:** Numerous fiscal and other constraints prohibited the CVNX Program Office and other participating Navy organizations from exploring the implications of a carrier designed solely for the operation of Short Takeoff, Vertical Landing (STOVL) aircraft, yet such a design would both force and permit significant deviations from recent past carrier design practice. Under this project, the investigators guided the student-performed design of a STOVL aircraft carrier. In addition to exploring the implications for ship and flight deck size and architectures, the effort included exploration of innovative approaches to reduced flight deck manning and increased aircraft ordnance handling. The final design report was made available widely within the Navy community supporting the Program Office.

#### **PUBLICATION:**

Calvano, C.N., Harney, R.C., et al., "A Short Take-Off/Vertical Landing (STOVL) Aircraft Carrier," Naval Postgraduate School Technical Report, NPS-ME-98-003, May 1998.

**DoD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles – Ships and Watercraft

**KEYWORDS:** Aircraft Carrier, STOVL, Ship Design

### **TOTAL SHIP AND BATTLE FORCE SURVIVABILITY STUDIES AT THE NAVAL POSTGRADUATE SCHOOL**

**Charles N. Calvano, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Chief of Naval Operations (N86DC)**

**OBJECTIVE:** To explore the viability of and begin the implementation of a research and teaching program which explores methods for improving U.S. Navy ship and battle force survivability and which makes increased knowledge and expertise of serving Navy officers an integral part of the program. To be guided by the reasons for this work, which include:

- The Navy will operate in the littorals where clutter is high and defense in depth is difficult;
- Increasingly sophisticated weapons are available to a growing number of nations;
- The nature of modern weapons, coupled with operations in the littorals, results in drastically reduced reaction times, making susceptibility reduction more difficult and the need for vulnerability reduction more acute;
- Budgetary pressures resulting in smaller numbers of Navy ships make the ability of the ships that are built to survive and continue to fight of greater importance; and
- Protecting the lives of U.S. sailors, always of utmost importance, takes on increasing criticality as the U.S. becomes more intolerant of casualties. Even if ships are hit or lost, the crew's ability to survive must be enhanced.

**SUMMARY:** The investigator has undertaken the organization of a Surface Ship Survivability Resource Center at NPS, obtaining statements of interest from 14 faculty members in several departments. Working with these other researchers in ship-survivability-related areas, areas of potentially high payoff for more intensive application of effort are being identified. Opportunities to combine and coordinate research in disparate areas and promote useful synergies have begun to be identi-

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fied. Liaison with the CVXN (formerly CVX) program office has identified certain damaged ship stability concerns that lend themselves to further exploration via simulation at NPS and this work is now being defined. Groundwork has been laid and an outline developed for the writing of a Fleet Survivability Handbook to be made available to all Navy surface ships, with the book to be co-authored by the investigator.

**DoD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles – Ships and Watercraft

**KEYWORDS:** Ship Survivability, Progressive Flooding, Damaged Stability

### MODELING OF PROGRESSIVE FLOODING DYNAMICS USING SIMULINK®

**Charles N. Calvano, Associate Professor**

**Fotis A. Papoulias, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** To complement work being done for OPNAV N86D using SIMSMART software to model progressive flooding by exploring the use of MATLAB and SIMULINK software for similar work and evaluate the relative utility, viability and user-friendliness of the two approaches. To simulate a ship with a compartment opened to the sea, with the bounding watertight bulkheads damaged. To incorporate human responses and decision-making results and explore various combinations and levels of flooding damage, to include the use of de-watering pumps and systems with varied configurations.

**SUMMARY:** The study to date concluded that: (1) The computational power of MATLAB can be combined with the ease of implementation of SIMULINK in order to set the fundamentals for a user friendly, modular, and expandable ship progressive flooding design tool. This approach has the added advantage of evaluating the degree of accuracy versus difficulty of implementation during each program upgrade. Extension to arbitrary ship compartment geometries is feasible through the use of lookup tables; (2) Since SIMULINK lacks the internal description of piping properties and de-watering pump characteristics, which SIMSMART possesses, it is necessary to build a collection of standard blocks which will contain a mathematical description of these properties. This will become a “library” which will be accessible to the end user from within the SIMULINK graphical environment. The standard pump characteristics library will be as identical as possible to the library that has been developed for NAVSEA and has been incorporated in the simulation package SIMSMART; and (3) The complete package of MATLAB functions and SIMULINK block diagrams will be accessible from a user friendly Graphical User Interface (GUI) with the appropriate callback functions. In this way, the complete system will be event driven and will be used in order to establish or assess the effectiveness of various countermeasure actions.

**DoD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles – Ships and Watercraft

**KEYWORDS:** Ship Survivability, Progressive Flooding, Damaged Stability

### COMPUTER OPTIMIZATION TECHNIQUES AS A TOOL FOR SHIP DESIGN

**Charles N. Calvano, Associate Professor**

**Matthew D. Kelleher, Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** The existing MIT Ship Synthesis Model estimates important characteristics of existing and conceptual surface displacement ships for engineering design and synthesis. The operator chooses the payload and certain gross characteristics of the ship and the computer model determines whether a design which meets these characteristics is feasible. If not, the operator chooses different characteristics and tries again. When a feasible design is arrived at, there is no indication of if, or how nearly, the design approaches an optimum. This work combines the MIT model, as the integration

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“engine,” with numerical optimization techniques to explore the possibility of producing a tool which arrives at a design which is both feasible and optimum for a given payload.

**SUMMARY:** The MIT model, written in the MATHCAD personal computer language was coupled with the MATLAB computing environment where the optimization calculations were performed. The MATHCONNEX module available with MATHCAD Professional, Version 7 or later, was used as the medium for integrating the software packages. The Integrated Ship Design Software produced under this effort uses Microsoft Excel to determine the weight and volume characteristics of a specified payload and uses these as inputs to the MIT model in MATHCAD, where an initial ship design is produced. An optimization package, based on existing MATLAB optimization tools was developed and integrated with the other modules to allow the output from the MIT model to be optimized based on a minimum displacement objective function and subject to the same constraints applied in the MIT model. The optimized characteristics are then returned to the MIT model in MATHCAD, where the characteristics of the optimized model are verified. The accuracy and robustness of the model produced were verified using a series of extreme design starting points and, in each case, with a given payload, the same optimum point was arrived at. Future work by the investigators will attempt to apply the model with optimization objective functions based on characteristics other than displacement, such as cost, or a combination of cost and displacement.

### THESIS DIRECTED:

Meister, Neil, “Application of Numerical Optimization Techniques to Surface Combatant Design Synthesis,” Master’s Thesis, Naval Postgraduate School, September 1998.

**DoD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles – Ships and Watercraft

**KEYWORDS:** Ship Design, Combatant Design, Optimization

## TARGET ACQUISITION MODEL EVALUATION

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsor: U.S. Army Training and Doctrine Analysis Command-Monterey**

**OBJECTIVE:** To update a previous version of the Handbook, and include recently found work on the U.K. Oracle Visual Performance Model.

**SUMMARY:** The Handbook is intended to support the Target Acquisition Models Library under development by Australia, Britain, Canada, and America (ABCA). The library will research, collate and document target acquisition models available to modelers so that the selection of a specific model for a particular combat simulation is enhanced. This work completes release 1.1 of the Handbook, summarizing and documents seven of the most widely used models.

### PUBLICATION:

Driels, Morris, “Handbook of Target Acquisition Models Release 1.1,” U.S. Army Training and Doctrine Analysis Command-Monterey, 1998.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Software, Target Acquisition, Combat Models

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### TARGET ACQUISITION MODULE UPDATE

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsors: Joint Technical Coordinating Group-Eglin Air Force Base and Naval Postgraduate School**

**OBJECTIVE:** To develop and enhance the target acquisition to the Joint Air to surface Weaponing System – JAWS.

**SUMMARY:** A stand-alone module was developed in FY97 and validated against data and other sources. In FY98, this program was interfaced with the JAWS database, and included in JAWS version 2.0, due for release in 1999. In transitioning from an analyst's model to a user model, the inputs were made more operationally relevant, and data imported directly from the weaponing part of the program.

This research program is on going, and will be extended into FY99. The planned work will be to complete the integration of the current TA module into JAWS, and extend it to cover FLIR sensors.

#### **OTHER:**

Driels, Morris, "JMEM Target Acquisition Program Analyst's Manual."

Driels, Morris, "Target Acquisition Program User Guide."

Driels, Morris, "JAWS Target Acquisition Program."

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Software, Target Acquisition

### AIR-TO-SURFACE AND SURFACE-TO-SURFACE TARGET ACQUISITION METHODOLOGIES

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsor: Joint Technical Coordinating Group-Army Materiel Systems Analysis Activity**

**OBJECTIVE:** To develop a high-fidelity target acquisition and mission-planning program.

**SUMMARY:** This program uses target imagery, and a DTED terrain data base to define local natural features in the vicinity of a specific target which will be attacked by aircraft. Cultural features are then raised up from the terrain to provide detailed masking contours, based on the approach angle and altitude of the attacking aircraft. The user then types in data regarding the weapon to be used and the program generates release conditions for the attack. In addition, a perspective view allows pilots to visualize the target area at a user-specified range.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Software, Target Acquisition

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### IMPLEMENTATION OF THE DELPHI TARGET ACQUISITION MODEL

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsor: U.S. Army Training and Doctrine Analysis Command-Monterey**

**OBJECTIVE:** To further refine earlier work on the development of a visual performance model based on a public domain version of the BAe ORACLE model.

**SUMMARY:** Previous work in FY97 laid the theoretical basis for the foveal component of a visual performance model based on proprietary work in the UK. This phase of the work completed the development of the model and allowed it to be compared to the U.S. Acquire model. In addition, work was done on the peripheral channel, allowing the development of a search component.

#### CONFERENCE PRESENTATION:

Driels, Morris, "An Investigation into the Public Domain Basis for the BAe ORACLE Visual Performance Model," 1998 Acquisition and Simulation (ACQSIM) Meeting, White Sands Missile Range, NM, June 1998.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Software, Target Acquisition, Combat Models

### REVIEW OF DELIVERY ACCURACY METHODOLOGY

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsor: Joint Technical Coordinating Group-Eglin Air Force Base**

**OBJECTIVE:** To review the algorithms used for assessing the accuracy of guided weapons.

**SUMMARY:** The standard methodologies used to determine statistical descriptions of weapon accuracy was applied to a new class of GPS/INS guided weapon. Using field data, the accuracy was described in a manner allowing it to be included into the Joint Air to surface Weaponing System JAWS. In doing so several issues regarding the methodology were highlighted, and improvements made. This work will be continued into FY99.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Software, Target Acquisition

### SCALABLE SEARCH METRICS

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsor: U.S. Army Training and Doctrine Analysis Command-Monterey**

**OBJECTIVE:** To assist in the development of a way to characterize eye movements over a field of regard which does not rely on spatial segmentation of fixed size bins.

**SUMMARY:** This was a collaborative project with UC Berkeley, where Professor Stark's team had a proposed way to define spatial locations within a field of regard. This allows eye movements to be specified in terms of these locations, rather than segmenting the image into regions of fixed size. This allows the scanpath to be defined independently of the segmentation sizes, and leads to a way of describing search that is applicable to mere general imagery.

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**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Human Vision, Search, Target Detection

### **CREEP OF FIBER REINFORCED METAL MATRIX COMPOSITES**

**Indranath Dutta, Associate Professor**

**Department of Mechanical Engineering**

**Sponsors: National Science Foundation and Naval Postgraduate School**

**OBJECTIVE:** To investigate the mechanisms of creep in metal-matrix composites.

**SUMMARY:** The goal of this project is to develop a phenomenological understanding of the mechanisms operative during high temperature deformation of metal matrix composites reinforced by continuous fibers. A combination of experimental and analytical means are being utilized to develop a model for creep/thermal cycling, with the eventual objective of generating transient deformation mechanism maps.

#### **PUBLICATIONS:**

Dutta, I. and Funn, J.E., "Creep Behavior of Interfaces in Fiber Reinforced Metal-Matrix Composites," *Acta Materialia*, Vol. 47, No. 1, pp. 149-164, January 1999.

Nagarajan, R., Dutta, I., Funn, J.V., and Esmele, M., "Role of Interfacial Sliding on the Longitudinal Creep Response of Continuous Fiber Reinforced Metal-Matrix Composites," *Materials Science and Engineering A*, Vol. 259, Issue 2, pp. 237-252, January 1999.

Nagarajan, R., Dutta, I., Funn, J.V., and Esmele, M., "Role of Interfacial Sliding on the Longitudinal Creep Response of Continuous Fiber Reinforced Metal-Matrix Composites," *Proceedings of the 127th TMS Annual Meeting*, San Antonio, TX, 15-19 February 1998.

#### **CONFERENCE PRESENTATION:**

Nagarajan, R., Dutta, I., Funn, J.V., and Esmele, M., "Role of Interfacial Sliding on the Longitudinal Creep Response of Continuous Fiber Reinforced Metal-Matrix Composites," 127th TMS Annual Meeting, San Antonio, TX, 15-19 February 1998.

#### **OTHER:**

Dutta, I., "Role of the Near Interface Region in Creep and Fracture of Metal-Matrix Composite," invited seminar at Los Alamos National Laboratory, April 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Composite, Creep, Interfacial Sliding

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### PROCESSING AND FRACTURE OF PARTICULATE REINFORCED METAL-MATRIX COMPOSITES

**Indranath Dutta, Associate Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Air Force Research Laboratory**

**OBJECTIVE:** To correlate processing, microstructure, and fracture properties in particulate reinforced aluminum (PRA) composites.

**SUMMARY:** The purpose of this project is to investigate microstructural development during processing of PRA, specifically with respect to the evolution of particulate distribution and matrix grain and precipitate structure, and to evaluate the impact of fracture properties and mechanisms. The eventual goal is to design the material microstructure in such a way so as to result in substantially improved fracture toughness, while retaining the stiffness and strength advantage of PRA relative to unreinforced aluminum alloys.

#### PUBLICATIONS:

Dutta, I., Quiles, F.N., McNelley, T.R., and Nagarajan, R., "Optimization of the Strength-Fracture Toughness Relation in Particulate Reinforced Al Composites via Control of Matrix Microstructure," *Metallurgical and Materials Transactions A*, 29A, p. 2433, 1998.

Chakravartty, J.K., Nagarajan, R., Dutta, I., and McNelley, T.R., "Improvement of Fracture Behavior of SiCp-Al Composites by Tailoring Matrix Microstructure," *Proceedings of the 1998 TMS Fall Meeting*, Rosemont, IL, 11-15 October 1998.

Dutta, I. and McNelley, T.R., "Matrix Effects on Deformation and Fracture of Discontinuously Reinforced Aluminum (DRA) Composites," *Proceedings of the ASM Materials Week 98*, Rosemont, IL, 11-15 October 1998.

#### CONFERENCE PRESENTATIONS:

Chakravartty, J.K., Nagarajan, R., Dutta, I., and McNelley, T.R., "Improvement of Fracture Behavior of SiCp-Al Composites by Tailoring Matrix Microstructure," 1998 TMS Fall Meeting, Rosemont, IL, 11-15 October 1998.

Dutta, I. and McNelley, T.R., "Matrix Effects on Deformation and Fracture of Discontinuously Reinforced Aluminum (DRA) Composites," ASM Materials Week 98, Rosemont, IL, 11-15 October 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Composites, Fracture, Matrix Microstructure

### METALLIZATION OF CVD DIAMOND FOR ELECTRONIC PACKAGING

**Indranath Dutta, Associate Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Unfunded**

**OBJECTIVE:** To develop approaches for metallization of CVD Diamond.

**SUMMARY:** The purpose of this project is to develop innovative approaches for producing adherent metallizations on CVD Diamond, which is an excellent thermal management material that is being currently considered for high-end electronic packages. Since metals do not naturally adhere to diamond, there is a need to develop new surface modifications for diamond to make metals stick to diamond.



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### PUBLICATION:

Menon, E.S.K. and Dutta, I., "Processing and Characterization of Alumina Thin Films on CVD Diamond Substrates for Producing Adherent Metallizations," *Journal of Material Research*, 14, p.359, 1999.

### OTHER:

Dutta, I. and Menon, S.K., "Surface Modification of Synthetic Diamond for Producing Adherent Thick and Thin Film Metallizations for Electronic Packaging," U.S. Patent # 5, 853, 888, 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Electronic Packaging, Diamond, Metallization

### MICROSTRUCTURES AND MECHANICAL PROPERTIES OF HIGH-STRENGTH, LOW-ALLOY (HSLA) STEELS AND THEIR WELDMENTS

Alan G. Fox, Professor

E.S.K. Menon, Research Associate Professor

M. Saunders, National Research Council Postdoctoral Research Associate

Center for Materials Science and Engineering

Department of Mechanical Engineering

Sponsors: Naval Surface Warfare Center-Cardero Division, Office of Naval Research,  
Naval Research Laboratory, and Naval Postgraduate School

**OBJECTIVE:** To investigate the microstructure and mechanical properties of ULC, HY, and HSLA 80-130 series steels and their weldments to evaluate new weld consumables and parent steels for Naval shipbuilding applications.

**SUMMARY:** In recent years the U.S. Navy has been replacing the HY80-100 series of high strength alloy steels with their high-strength, low-alloy (HSLA) equivalents. This is being done because the stringent weld pre-heat requirements associated with the HY steels are not necessary for the HSLA series. So, despite the higher manufacturing costs of high-strength, low-alloy steels, the U.S. Navy should make significant savings by changing over to HSLA or ultra low carbon (ULC) steels for ship and submarine construction. In order to extract the maximum benefit from these newly developed steels it is also necessary to develop improved weld filler wires. This project supports these objectives with fundamental physical metallurgy studies at NPS using advanced optical and electron microscopy techniques.

### PUBLICATIONS:

Blackburn, J.M., Brandemarte, A., and Fox, A.G., "The Effect of Inclusions and Austenite Grain Size on the CVN Impact Behavior of a Newly Developed Low-Carbon Steel Weld Metal," *Proceedings of the Third Pacific Rim International Conference*, 1998.

Menon, E.S.K., Fox, A.G., and Spanos, G., "Carbon in Retained Austenite," *Proceedings of the Electron Microscopy 1998 (ICEM 14)*, pp. 211-212, Cancun, Mexico, 31 August-4 September 1998.

### CONFERENCE PRESENTATIONS:

Blackburn, J.M., Brandemarte, A., and Fox, A.G., "The Effect of Inclusions and Austenite Grain Size on the CVN Impact Behavior of a Newly Developed Low-Carbon Steel Weld Metal," Third Pacific Rim International Conference, 1998.

Menon, E.S.K., Fox, A.G., and Spanos, G., "Carbon in Retained Austenite," Electron Microscopy 1998 (ICEM 14, Cancun, Mexico, 31 August-4 September 1998.



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### THESIS DIRECTED:

Walters, J.D., "Microchemical Analysis of Non-Metallic Inclusions in C-Mn Steel Shielded Metal Arc Weld Metals by Analytical Transmission Electron Microscopy," Master's Thesis, Naval Postgraduate School, June 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Ultra Low Carbon Steel, Welding

### CHEMISTRY, MICROSTRUCTURE, AND DUCTILITY OF Ti-44Al-11Nb ALLOYS

Alan G. Fox, Professor

E.S.K. Menon, Research Associate Professor

Center for Materials Science and Engineering

Department of Mechanical Engineering

Sponsors: Naval Air Warfare Center-Patuxent River and Naval Postgraduate School

**OBJECTIVE:** To investigate the microstructure of Ti-44Al-11Nb alloys by optical, scanning, and transmission electron microscopies with a view to understanding the improved ductility that results from adding Nb to  $\gamma$ -TiAl alloys.

**SUMMARY:** The overall objective of this research is to quantitatively correlate the microstructure and chemical composition of the various phases, the interfaces between them and the grain boundaries between like phases in a Ti-44Al-11Nb alloy in the as-processed condition using optical, scanning, and scanning transmission electron microscopies. In particular, the effects of alloying element segregation to grain boundaries and interfaces between different phases will be carefully studied. This includes oxygen and boron which are usually present in significant amounts in TiAl alloys and, since they are small atoms, they can rapidly segregate to grain boundaries and interfaces during processing. This analysis of the nature of microstructure, segregation, and interfaces in Ti-44Al-11Nb will hopefully allow an understanding of why Nb additions and certain processing conditions lead to improved ductilities in these alloy systems.

### THESIS DIRECTED:

Halladay, T., "The Microstructure of Directionally Solidified Ti-44-11Nb Alloy," Master's Thesis, Naval Postgraduate School, December 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Ductility of Ti-Al-Nb Alloys, Optical and Electron Microscopy

### MICROSTRUCTURAL STUDIES OF SILICON FIBER REINFORCED GLASS-CERAMIC COMPOSITES FOR GAS TURBINE APPLICATIONS

A.G. Fox, Professor

E.S.K. Menon, Research Associate Professor

N. Rajagopalan, National Research Council Postdoctoral Research Associate

Center for Materials Science and Engineering

Department of Mechanical Engineering

Sponsors: Systran Corp., Air Force Research Laboratory, and Naval Postgraduate School

**OBJECTIVE:** To investigate the microstructure of silicon fiber reinforced glass-ceramic matrix composites.

**SUMMARY:** The U.S. Navy and Air Force have ongoing programs of research into silicon fiber reinforced glass-ceramic matrix composites (CMCs) which have many potential uses for gas turbine components. The high strength, toughness and

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resistance to high temperatures and low density of CMCs could allow a considerable increase in gas turbine engine efficiency if they could be used to replace heavy metallic parts. Unfortunately, aircraft operating environments are often very severe and any CMC components developed must be resistant to high temperature environments containing salt and aviation fuel which may be rich in sulfur. This work is using electron microscopy and x-ray diffraction to elucidate the microstructure of new glass-ceramic matrix composites which are capable of operating in severe environments.

### PUBLICATION:

Kumar, A. and Fox, A.G., "Hot Corrosion of a Calcium Aluminosilicate Glass-Ceramic and a Si-C-O Fiber-Reinforced Calcium Aluminosilicate Matrix Composite," *Journal of the American Ceramic Society*, Vol. 81, pp. 613-623, 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Electron Microscopy, X-Ray Diffraction, Fiber-Reinforced Glass-Ceramic Matrix Composites

### QUANTITATIVE AND QUALITATIVE PEELS AND EDX SPECTROSCOPY USING THE NPS TRANSMISSION ELECTRON MICROSCOPE

Alan G. Fox, Professor

E.S.K. Menon, Research Associate Professor

M. Saunders, National Research Council Postdoctoral Research Associate

R. Hashimoto, Materials Technician

Center for Materials Science and Engineering

Department of Mechanical Engineering

Sponsor: Unfunded

**OBJECTIVE:** To investigate the capability of the NPS Topcon 002B transmission electron microscope (TEM) and to perform both quantitative and qualitative parallel electron energy loss spectroscopy (PEELS) and energy dispersive x-ray (EDX) spectroscopy.

**SUMMARY:** Parallel electron energy loss spectroscopy (PEELS) and energy dispersive x-ray (EDX) spectroscopy are commonly used to obtain microchemical information in the transmission electron microscope (TEM). Indeed most of the TEM research carried out in the Center for Materials Science and Engineering involves the use of PEELS or EDX to some extent. It has been found that novel techniques for treating PEELS and EDX data, including the use of multivariate statistical analysis, can provide important chemical information about interfaces in multiphase systems. Recently an EMiSPEC vision system was installed on the Topcon 002B TEM and this will allow simultaneous acquisition of EDX and PEELS spectra to be made which will significantly improve the capability to perform quantitative EDX and PEELS.

### PUBLICATIONS:

Saunders, M., Menon, E.S.K., Chisholm, D.J., and Fox, A.G., "Extracting Chemical Information from Energy-Dispersive X-Ray Spectra by Multivariate Statistical Analysis," *Proceedings of Microscopy and Microanalysis 1998*, pp. 204-205, Atlanta, GA, 12-16 July 1998.

Saunders, M., Menon, E.S.K., and Fox, A.G., "Using Statistical Methods to Identify and Map Interface Reaction Phases from EDS Spectra," *Proceedings of Electron Microscopy 1998* (ICEM 14), pp. 598-598, Cancun, Mexico, 31 August-4 September 1998.

Saunders, M., Menon, E.S.K., Hashimoto, R.Y., and Fox, A.G., "Interface Electron Energy Loss Spectroscopy (EELS) Analysis: Comparison of Spatial Difference and Multivariate Statistical Analysis (MSA) Techniques," *Proceedings of Electron Microscopy 1998* (ICEM 14), pp. 571-572, Cancun, Mexico, 31 August-4 September 1998.

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Saunders M., Menon E.S.K., and Fox A.G., "Determination of Interface Composition Variations by the Application of Multivariate Statistical Analysis to Energy Dispersive X-Ray Spectra and Electron Energy Loss Spectra," *Proceedings of Scandem 98*, Helsinki, Finland, July 1998.

### CONFERENCE PRESENTATIONS:

Saunders, M., Menon, E.S.K., Chisholm, D.J., and Fox, A.G., "Extracting Chemical Information from Energy-Dispersive X-Ray Spectra by Multivariate Statistical Analysis," *Microscopy and Microanalysis 1998*, Atlanta, GA, 12-16 July 1998.

Saunders, M., Menon, E.S.K., and Fox, A.G., "Using Statistical Methods to Identify and Map Interface Reaction Phases from EDS Spectra," *Electron Microscopy 1998 (ICEM 14)*, Cancun, Mexico, 31 August-4 September 1998.

Saunders, M., Menon, E.S.K., Hashimoto, R.Y., and Fox, A.G., "Interface Electron Energy Loss Spectroscopy (EELS) Analysis: Comparison of Spatial Difference and Multivariate Statistical Analysis (MSA) Techniques," *Electron Microscopy 1998 (ICEM 14)*, Cancun, Mexico, 31 August-4 September 1998.

Saunders, M., Menon, E.S.K., and Fox, A.G., "Determination of Interface Composition Variations by the Application of Multivariate Statistical Analysis to Energy Dispersive X-Ray Spectra and Electron Energy Loss Spectra," *Scandem 98*, Helsinki, Finland, July 1998.

### THESIS DIRECTED:

Chisholm, D.J., "Use of Principal Component Analysis for the Identification and Mapping of Phases from Energy Dispersive X-Ray Spectra," Master's Thesis, Naval Postgraduate School, December 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Transmission Electron Microscopy, PEELS, EDX

## EVALUATION OF THE INFLUENCE OF WATER TEMPERATURE ON CRACKING IN UNDERWATER WET WELDS

**Alan G. Fox, Professor**

**E.S.K. Menon, Research Associate Professor**

**Center for Materials Science and Engineering**

**Department of Mechanical Engineering**

**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** To investigate the underbead cracking present in the heat affected zones of underwater shielded metal arc weldments.

**SUMMARY:** In recent years the U.S. Navy has been making a concerted effort to reduce maintenance costs, in particular the costs of dry docking. As a result, attempts are currently being made to underwater wet weld structural steels with carbon equivalents of 0.4 or less. Unfortunately, in fully restrained situations, it has proved difficult to produce such weldments without underbead cracking especially in low temperature water (less than 10 C). In this work fully restrained underwater wet welds are being produced on ASTM A516 Grade 70 steel under carefully controlled conditions at different temperatures. The microstructure and thermal history of these weldments is being carefully monitored in order that the precise mechanism of cracking can be understood.

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### PUBLICATION:

Fox, A.G., Johnson, R.L., and Dill, J.F., "The Effect of Water Temperature on the Underwater Wet Weldability of ASTM A516 Grade 70 Steel," *Proceedings of the 17th International Conference on Offshore Mechanics and Arctic Engineering*, pp. 2262-2267, Lisbon, Portugal, 5-9 July 1998.

### CONFERENCE PRESENTATION:

Fox, A.G., Johnson, R.L., and Dill, J.F., "The Effect of Water Temperature on the Underwater Wet Weldability of ASTM A516 Grade 70 Steel," 17th International Conference on Offshore Mechanics and Arctic Engineering, Lisbon, Portugal, 5-9 July 1998.

### THESIS DIRECTED:

Manning, R.D., "Analysis of Underbead Cracking in Underwater Wet Weldments on A516 Grade 70 Steel," Master's Thesis, Naval Postgraduate School, September 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Underwater Wet Welding, Underbead Cracking, Hydrogen Induced Cracking

### DIFFRACTION METHODS FOR THE ACCURATE MEASUREMENT OF STRUCTURE FACTORS AND CHARGE DENSITIES OF ELEMENTS AND INTERMETALLIC ALLOYS

Alan G. Fox, Professor

E.S.K. Menon, Research Associate Professor

M. Saunders, National Research Council Postdoctoral Associate

Center for Materials Science and Engineering

Department of Mechanical Engineering

Sponsors: Wright-Patterson Air Force Base, Naval Air Warfare Center-Patuxent River,  
and Naval Postgraduate School

**OBJECTIVE:** To accurately measure the low-angle structure factors of elements and alloys by various diffraction methods so that their electronic bonding mechanisms can be investigated.

**SUMMARY:** A knowledge of the distribution of bonding electrons in crystalline solids can give important information about their physical properties. One way to gain such knowledge is to accurately measure the low-angle structure factors of the materials of interest by some means, and then use these to generate maps of the electron charge distributions. In the past both electron and x-ray diffraction have been used to measure the low-angle structure factors of several elements and intermetallic alloys with high accuracy. The lattice parameters and Debye-Waller factors were measured by x-ray diffraction and the structure factors by the critical voltage technique in electron diffraction. More recently these measurements have been made using the energy filtering transmission electron microscope which has been recently installed at NPS. This has allowed fully quantifying energy filtered convergent beam electron diffraction patterns and determining the low-angle structure factors of elements and alloys with an accuracy far greater than previously achieved and, in addition, it has been shown that it is possible to measure Debye-Waller factors by this method. This is leading to a vastly improved understanding of the nature of bonding in crystalline solids.

### PUBLICATIONS:

Fox, A.G. and Menon, E.S.K., "Debye-Waller Factors of Stoichiometric and Al-rich  $\gamma$ -TiAl Alloys," *Philosophical Magazine A*, Vol. 77, pp. 577-592, 1998.

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## PROJECT SUMMARIES

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Saunders, M., Menon, E.S.K., and Fox, A.G., "Quantitative Convergent Beam Electron Diffraction (CBED) Studies of Metals and Alloys," *Proceedings of Electron Microscopy 1998 (ICEM 14)*, pp. 779-780, Cancun, Mexico, 31 August-4 September 1998.

### CONFERENCE PRESENTATION:

Saunders, M., Menon, E.S.K., and Fox, A.G., "Quantitative Convergent Beam Electron Diffraction (CBED) Studies of Metals and Alloys," *Electron Microscopy 1998 (ICEM 14)*, Cancun, Mexico, 31 August-4 September 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Convergent Beam Electron Diffraction, Structure Factor Measurement, Bonding Charge Density

### **THERMOACOUSTIC EFFECTS AT A SOLID-FLUID BOUNDARY: THE ROLE OF A SECOND ORDER THERMAL EXPANSION COEFFICIENT**

**Ashok Gopinath, Assistant Professor  
Department of Mechanical Engineering**

**Sponsor: National Aeronautics and Space Administration-Lewis Research Center**

**OBJECTIVE:** To conduct fundamental material and transport studies on thermoacoustic phenomena in microgravity with future application to thermodynamic engines aboard the Space Station.

**SUMMARY:** An analytical study has been conducted of the thermoacoustic effects induced by the interaction of a strong acoustic field with a rigid boundary such as that in a thermoacoustic engine. With the sphere as a representative object, it's been found that the acoustic field can create a spatially periodic heating and cooling pattern on its surface just as in the stack of a thermoacoustic engine. The thermoacoustic effects are generated primarily in the narrow Stokes boundary layer region on the sphere and are diffused and convected over the remaining part of the fluid domain. The unexpected role of a second-order thermal expansion coefficient in this process is explained.

### **PUBLICATIONS:**

Gopinath, A., Tait, N.L., and Garrett, S.L., "Thermoacoustic Streaming in a Resonant Channel: the Time-Averaged Temperature Distribution," *Journal of the Acoustical Society of America*, Vol.103, No.3, pp.1388-1405, March 1998.

Gopinath, A., "Thermoacoustic Streaming from a Rigid Sphere," in review.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Materials, Basic Science)

**KEYWORDS:** Thermoacoustics, Acoustic Streaming, Acoustic Levitation, Thermophysical Property Measurement, Thermodynamic Moduli, Oscillatory Flows, Asymptotic Techniques

### **ACOUSTIC STREAMING IN MICROGRAVITY: FLOW STABILITY AND HEAT TRANSFER ENHANCEMENT**

**Ashok Gopinath, Assistant Professor  
Department of Mechanical Engineering**

**Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory**

**OBJECTIVE:** To conduct fundamental material and transport studies on the role of acoustic streaming in enhancing transport rates in microgravity with application to materials processing.

## PROJECT SUMMARIES

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**SUMMARY:** Analytical studies have been conducted on the role of steady streaming in enhancing heat and mass transport rates in a zero-mean acoustic field under microgravity conditions. In particular the compressible flow situation has been considered for which the object in question in the acoustic field is non-compact. This requires a Helmholtz decomposition of the vector velocity field requiring the solution of both a velocity potential and a stream function. The streaming flow pattern indicates some unique features resulting from the nonlinear interaction of both the rotational and irrotational velocity fields. Some preliminary numerical studies (on steady flows) based on the spectral method have also been initiated with the goal of application to oscillatory flows.

### PUBLICATIONS:

Gopinath, A. and Harder, D.H., "An Experimental Study of Heat Transfer from a Cylinder in Low-Amplitude Oscillatory Flows," *International Journal of Heat and Mass Transfer*, to appear.

Gopinath, A. and Bridenstine, M., "An Experimental Study of Heat Transfer from a Cylinder in High-Amplitude Oscillatory Flows," in review.

Gopinath, A. and Trinh, E., "Steady Streaming from a Non-Compact Sphere," abstract, *Journal of the Acoustical Society of America*, Vol.103, No.5, Pt.2, p.2763, May 1998.

### CONFERENCE PRESENTATIONS:

Gopinath, A. and Trinh, E., "Steady Streaming from a Non-Compact Sphere," 16<sup>th</sup> International Congress on Acoustics and 135<sup>th</sup> Meeting of the Acoustical Society of America, Seattle, WA, June 1998.

Gopinath, A., "Thermoacoustic Effects at a Solid-Fluid Boundary," 4<sup>th</sup> NASA Microgravity Fluid Physics and Transport Phenomena Conference, Cleveland, OH, August 1998.

**DoD KEY TECHNOLOGY AREA:** Other (Energy Systems)

**KEYWORDS:** Acoustic Streaming, Heat Transport, Asymptotic Techniques

## FURTHER EVALUATION OF TEMPERATURE ON CRACKING OF UNDERWATER WELDS

Ashok Gopinath, Assistant Professor

Alan G. Fox, Professor

Department of Mechanical Engineering

Sponsor: Naval Sea Systems Command

**OBJECTIVE:** To understand the role of water temperature and cooling on the rapid heat transfer rates in determining the material structure and strength of underwater welds.

**SUMMARY:** The rapid cooling rates encountered in underwater wet welding are crucial in determining the resulting material structure and strength of the welded joints. A numerical model was developed to determine the three-dimensional conduction based temperature distribution in a thick plate being welded underwater. A fully implicit finite-volume model was developed and a variable mesh size with temperature dependent transport properties was used. Boiling was (as expected) found to be the principal mode of heat transfer giving cooling times significantly lower than noted in the literature. However the cooling times themselves were not found to be sensitive to the water temperature.

### THESIS DIRECTED:

Isiklar, Y.V., "A Numerical Study of Heat Transfer Behavior in Welding," Master's Thesis, Naval Postgraduate School, June 1998.



## PROJECT SUMMARIES

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**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Underwater Wet Welding, Carbon Steels, Cracking, Heat Transfer, Ship Repair, Numerical Modeling

### ACOUSTIC MODELING OF HYDRODYNAMIC WAVE LOADING

**Ashok Gopinath, Assistant Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Naval Postgraduate School**

**OBJECTIVE:** To be able to use acoustics to simulate oscillatory wave loading on marine offshore structures.

**SUMMARY:** An experimental study was conducted to measure the forces on a cylinder in a standing acoustic field. The cylinder is representative of the leg of an offshore structure or platform, while the acoustic field is representative of the oscillatory wave loading on such a structure. The working fluid is high pressure nitrogen so chosen to reduce the viscosity to allow high values of the Reynolds number to be achieved. Both in-line (drag) and transverse (lift) coefficients have been measured and corroborated with existing data in the literature. The experimental technique appears to have promising potential for extension to larger values of the parameter regime which need further study.

#### THESIS DIRECTED:

Dufek, M., "Experimental Study of Zero Mean Oscillatory Flow Forces on Circular Cylinders," Master's Thesis, Naval Postgraduate School, March 1998.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Structures, Basic Science)

**KEYWORDS:** Hydrodynamic Loading, Fluid-Structure Interaction, Acoustics, Reynolds Number, Lift and Drag, Off-shore Marine Structures, Oscillatory Wave Loading

### LIQUID PHASE SINTER-FORMING OF CERAMICS

**Ashok Gopinath, Assistant Professor**  
**Indranath Dutta, Associate Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Unfunded**

**OBJECTIVE:** To study the feasibility of sinter-forming covalent ceramics using superplastic-like deformations.

**SUMMARY:** An unsponsored feasibility study has been initiated to explore the possibility of net-shape part formation from hard to machine materials such as (covalent) ceramics. The goal is to combine the processes of liquid phase sintering, and forming, in a novel manner and exploit a suitable process parameter window to effect the forming operation with superplastic-like strains. A suitable model ceramic system has been identified and the work of the first thesis student although preliminary has yielded promising results. The study is being continued by two additional students, particularly to explore the role of the intergranular liquid phase in supporting the tensile forces encountered during forming, and to understand the subsequent modes of failure.

#### THESIS DIRECTED:

Lloyd, J.M., "A Feasibility Study of Liquid Phase Sinter-Forming of a Model Ceramic System," Master's Thesis, Naval Postgraduate School, September 1998.



## PROJECT SUMMARIES

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**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Ceramic Powder Processing, Liquid Phase Sintering, High Temperature Deformation, Superplasticity

### EFFICIENT NONLINEAR TRANSIENT DYNAMIC ANALYSIS FOR STRUCTURAL OPTIMIZATION USING AN EXACT INTEGRAL EQUATION FORMULATION

**Joshua H. Gordis, Associate Professor**  
**Department of Mechanical Engineering**  
**Beny Neta, Professor**  
**Department of Mathematics**  
**Sponsor: National Science Foundation**

**OBJECTIVE:** This project is concerned with the theoretical development and computational implementation of a time domain theory for locally nonlinear transient structural synthesis. Application principally will be made to seismic isolation.

**SUMMARY:** This research concerns the continued development of a time domain theory for structural synthesis. This theory provides the previously unavailable capability of performing exact damped transient structural synthesis for systems with localized nonlinear components with the order of the synthesis being independent of model size. The method is based on Volterra integral equations derived from the convolution integral which describe substructure coupling and structural modification. Current results demonstrate an order of magnitude reduction in compute times as compared with widely-used commercial finite element analysis packages. The use of the formulation for the optimal design of seismic isolation is under development.

#### **PUBLICATION:**

Durant, B.R. and Gordis, J.H., "Time Domain Synthesis in the Optimal Design of Nonlinear Shock and Vibration Isolation for Large Structures," *Proceedings of the 69th Shock and Vibration Symposium*, Minneapolis, MN, 12-15 October 1998. (Also submitted to *Shock and Vibration*.)

#### **CONFERENCE PRESENTATION:**

Durant, B.R. and Gordis, J.H., "Time Domain Synthesis in the Optimal Design of Nonlinear Shock and Vibration Isolation for Large Structures," 69th Shock and Vibration Symposium, Minneapolis, MN, 12-15 October 1998.

#### **THESIS DIRECTED:**

Florence, D., "Optimal Design of Nonlinear Shock Isolation for Large, Locally Nonlinear Structures," Master's Thesis, Naval Postgraduate School, December 1998.

**DoD KEY TECHNOLOGY AREA:** Modeling and Simulation

**KEYWORDS:** Structural Dynamics, Transient Response, Synthesis, Nonlinear Dynamics, Seismic Isolation

## PROJECT SUMMARIES

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### STRUCTURAL DYNAMICS OF THE RAH-66 COMANCHE HELICOPTER

**Joshua H. Gordis, Associate Professor**  
**Department of Mechanical Engineering**

**E. Roberts Wood, Professor**  
**Department of Aeronautics and Astronautics**

**Don Danielson, Professor**  
**Department of Mathematics**

**Sponsors: U.S. Army Aviation and Technology Command and Naval Postgraduate School**

**OBJECTIVE:** Technical support is provided to the U.S. Army Aviation and Technology Command, St. Louis, for the structural dynamics and vibration of the RAH-66 Comanche.

**SUMMARY:** The RAH-66 Comanche helicopter is the U.S. Army's attack helicopter for the 21st Century. During 1995, the Comanche began a program of ground vibration and flight tests, intended to validate structural dynamic performance of the airframe and to demonstrate the helicopter's performance characteristics. These tests typically uncover dynamics problems with rotor-fuselage coupling and forced response. In order to ensure the survival of the Comanche program, these problems, when discovered, must be quickly resolved. This effort provides rapid technical support to the Comanche Program, to resolve structural dynamics problems. FY98 efforts focused on the identification of airloads on the empennage using a combination of flight test dynamic response data and fuselage finite element modeling.

#### **OTHER:**

Wood, E.R., Danielson, D.A., and Gordis, J.H., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," report submitted to Comanche Program Manager's Office, 1 January 1998 to 31 December 1998.

#### **THESIS DIRECTED:**

Mason, P.H., "Identification of Random Loads Impinging on the RAH-66 Comanche Helicopter Empennage Using Spectral Analysis," Master's Thesis, Naval Postgraduate School, June 1998.

**DoD KEY TECHNOLOGY AREA:** Air Vehicles

**KEYWORDS:** Helicopter, Comanche, Structural Dynamics

### BUGS: BASIC UNEXPLODED (UXO) GATHERING SYSTEM - MODELING AND SIMULATION

**Anthony J. Healey, Professor**  
**Joung K. Kim, Research Assistant**  
**Department of Mechanical Engineering**  
**Sponsor: Naval Ordnance Technical Center**

**OBJECTIVE:** This work is being undertaken to provide a modeling and simulation capability for evaluating the clearance performance of multiple cooperating vehicles in UXO gathering and minefield operations. The work involves the development and the evaluation of various robot system control concepts as proposed for the BUGS system and shallow water minefield.

**SUMMARY:** The graphics simulator code runs on a high end SGI workstation, currently an ONYX Reality Engine workstation, and has been developed using the "inventor" and "performer" tool kit. It is planned to use the simulator and its complementary modeling tools to evaluate sensor technology as well as control methodologies in relation to the performance of the overall BUGS/AUTORECORM system concepts for land-based ordnance clearance operations.

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## PROJECT SUMMARIES

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The simulator is built around a terrain base taken from the Marine Corps 29 Palms facility and a small subset of that data base has been selected as a test site for evaluation of clearance operations. Vegetation has been included as uniformly distributed randomly dispersed objects added to the data base.

Munitions simulated include Mk 118 anti-personnel mines, and “softball” and “baseball” munitions that would have been dispensed from an airborne canister. These munitions are randomly distributed around a nominal center with an average density, selectable by the user.

Clearance operations are then simulated by a fleet of vehicles (BUGS) that can be controlled to a speed, heading and altitude above ground command. Walking machines are rendered as full kinematically faithful hexapods walking with a double tripod fixed gait, where each bug has an arm (boom) to support a camera, tactile, or magnetic sensor. The sensor has a defined radius of detection so that if a munition is encountered, a command is registered in the machine controller to manipulate the boom and retrieve the object.

Search patterns can be simulated that are directed exhaustive searches if motion sensors are presumed to have sufficient accuracy for navigation to way points, or random searches if no navigation sensors are presumed to be available.

The characteristics of random versus exhaustive search including obstacle avoidance have been established as part of this research, and the influence of various levels of navigation sensor accuracy and “inter bug communication” on search effectiveness are being sought.

Recently, questions concerning the comparison of random search as opposed to supervised autonomous directed searches for both PUCA and minefield operations are being analyzed. The effectiveness of obstacle avoidance methodology, path planning, and autonomous map building techniques, and the comparison of wheeled and tracked vehicle locomotion methods are being studied.

Five scenarios have been studied in detail. These are: (1) a cluster of UXO being cleared by a fleet of robots (BUGS) using random searching; (2) field of clusters of differing densities; (3) clearance using an upgraded version of the EOD RECORM vehicle with optical sensing; and (4) cooperating behavior with AUTORECORM and a fleet of BUGS.

### **PUBLICATION:**

Healey, A.J. and Kim, J., “AUTORECORM Control Algorithms and Cooperative Behavior for Enhancing UXO Clearance,” Naval Postgraduate School Technical Report, NPS-ME-98-006, December 1998.

**DoD KEY TECHNOLOGY AREAS:** Simulation and Modeling, Other (Robotics, Mine Warfare)

**KEYWORDS:** Robotics, Simulation and Modeling, Mine Warfare

## **STUDIES IN INTELLIGENT CONTROL OF AUTONOMOUS VEHICLES**

**Anthony J. Healey, Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Ford Motor Company**

**OBJECTIVE:** This grant is in the support of research in the subject matter without restriction, and serves to aid the ongoing programs in the Center for Autonomous Underwater Vehicle Research.

**SUMMARY:** This project has supported the purchase of radio Ethernet communications devices and radio modem connections between the *Phoenix* robot and a shore based operator station. Also, it has supported the purchase of mobile laboratory equipment necessary to the deployment of *Phoenix* in Monterey Bay.

**DoD KEY TECHNOLOGY AREAS:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Autonomous Systems, Robotics, Vehicles, Navigation

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## PROJECT SUMMARIES

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### NAVIGATION OF REMOTE PLATFORMS

**Anthony J. Healey, Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Florida Atlantic University**

**OBJECTIVE:** This project is aimed at a cooperative study between NPS and Florida Atlantic University (FAU) with the purpose of developing theories and algorithms for the asynchronous data fusion of autonomous underwater vehicle (AUV) navigation sensory information.

**SUMMARY:** New navigation algorithms are needed for small AUV systems as they are limited in size and cost. Low cost sensor suites are less accurate than their higher cost counterparts, and their sensory data arrive at times that are not necessarily synchronized at control loop rates. With the new capabilities of networked embedded microprocessor systems, system control may be dispersed leading to distributed intelligent nodes that are capable of performing local area control functions coordinated by a higher level node. Sensory data arrive at arbitrary times when processed. For example, DGPS position data arrives at approximately 1 second intervals. Acoustic Doppler sonar returns when bottom locked, give information at about 2 Hz. Magnetic compass and inertial sensors for rotational rate may be available at high rates.

This work has developed a model-based Extended Kalman Filter provide position and other state estimates between updates using new data from all sensors as available. Bias and scale factor errors are included in the model and learned through the fusion of disparate sensors and compensated if constant.

Real time implementation in the QNX operating system on an embedded Pentium processor (with connectivity to Lon Works network protocols) as used by the FAU Ocean Voyager II AUV has been used to provide real time computability of the algorithms. It has been shown that filter computations are easily managed within the typical rates required for AUV navigation. Further real time implementation work into the FAU vehicles remains.

#### PUBLICATIONS:

Healey, A.J., An, E.P., and Marco, D.B., "On-Line Compensation of Heading Sensor Bias for Low Cost AUVs Using EKF," *Proceedings of IEEE AUV '98*, Cambridge, MA, 20-21 August 1998.

Yun, X., McGhee, R., Healey, A.J., et al., "Testing and Evaluation of an Integrated GPS/INS System for Small AUV Navigation," *IEEE Journal of Oceanic Engineering*, accepted for publication, 1998.

**DoD KEY TECHNOLOGY AREA:** Other (Robotics and Automation, Underwater Vehicles, Mine Countermeasures)

**KEYWORDS:** Autonomous Systems, Robotics, Vehicles, Navigation

### CONTROL ARCHITECTURES AND NON-LINEAR CONTROLLERS FOR UNMANNED UNDERWATER VEHICLES

**Anthony J. Healey, Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Office of Naval Research**

**OBJECTIVE:** This project is funded through ONR to jointly collaborate with researchers from Florida Atlantic University (FAU) and Virginia Polytechnic Institute (VPI) as part of a Multi-University Research Initiative to seek enhancements in robustness in control systems of interest to the Navy. Robustness will be sought through multi-level hierarchical control schemes using robust nonlinear servo control laws at the lowest level and discrete state switching using elastic constraint and fuzzy reasoning at higher levels.

**SUMMARY:** The work is just starting and collaborative discussions are ongoing between VPI, FAU, and NPS. The review of available simulation and modeling tools for UUV applications is beginning. Not only are existing simulation tools being

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## PROJECT SUMMARIES

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evaluated, but others used for both lower level servo control development such as MATLAB/SIMULINK but higher level simulation tools for the design of discrete state controllers using Petri Net methods and Finite State Machine simulators are being evaluated.

Robust nonlinear control methodology is expected to be used for ships underway replenishment, and at - sea transfer operations improvements, power electronic building block (PEBBS) systems, as well as for UUV and other underwater systems.

Building on robust control theory, this work has led to methodology for the automatic detection of subsystem faults arising from items such as control fin jams, or fin loss. Detection of faults is accomplished by a combination of model free and model-based methods using both sensor information as well as the analytical redundancy afforded by the model based filters.

**DoD KEY TECHNOLOGY AREA:** Other (Robotics and Automation, Underwater Vehicles, Control)

**KEYWORDS:** Autonomous Systems, Robotics, Vehicles, Nonlinear and Robust Control

### AUTOMATIC FAULT DETECTION AND CONTROL RECONFIGURATION

**Anthony J. Healey, Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Office of Naval Research**

**OBJECTIVE:** Long-term deployments of autonomous systems in the ocean require replenishment of energy supplies and reliable, fault free operation. It is recognized that fault free operation will not always be possible, so that system design must pay attention to a study of failure modes and their effects. In spite of the use of good engineering practice, faults can occur. Two kinds of “faults” identified are: (1) those that arise from malfunctions in the hardware and software subsystems in the vehicle and (2) those that arise from environmental conditions that are viewed as disturbances, and while these may not be directly “faults,” they have the effect that the completion of a mission is jeopardized.

An example of a hardware fault would be the loss of steering resulting from a stuck or loose fin. An example of a type 2 fault would be the inability of the vehicle to take a data measurement because of high sea state in shallow water operation.

To design a system that will automatically detect the presence of a “fault” is the subject of many papers. This problem is common to the aircraft, spacecraft, and process industries, and much has been written about methods available. In general we can classify the methods into those that use simple limits and trends analysis, those that use detection techniques but which are without the use of analytical models, and those that provide analytical models as the basis for detection filters. The detection of status signals such as battery voltage, motor winding temperature, computer bay temperatures, is relatively easy and accomplished by the comparison of the measured signal with a previously set threshold. Exceeding those thresholds indicates a fault condition for which some action is taken – for instance either to slow down the vehicle speed or to abort the mission and surface. The detection of dynamic signal faults is more complex and requires the design of specially constructed residual generators, and is the subject of this activity. Special application to the U.S. Navy’s 21 UUV vehicle is implied.

**SUMMARY:** A new fault detection architecture has been defined based on a bank of observers, decomposed by control mode and designed to be robust for residual generation. Residual processing is performed using maximum likelihood methodology and actuator faults have been detected and identified. Use of a fuzzy inference system has been proposed for performing the reconfiguration of actuator inputs so that a stable, but degraded control may still be achieved after fault occurrence.

### PUBLICATIONS:

Healey, A.J., “Analytical Redundancy and Fuzzy Inference in AUV Fault Detection and Compensation,” *Proceedings of Oceanology 1998*, 11-14 March, 1998, <http://web.nps.navy.mil/~me/healey/papers/oceanology98.pdf>.

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## PROJECT SUMMARIES

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Riedel, J.S. and Healey, A.J., "Model Based Predictive Control of AUVs for Station Keeping in a Shallow Water Wave Environment," *Proceedings of the International Advanced Robotics Program IARP 98*, 18 February 1998, [http://web.nps.navy.mil/~me/healey/papers/iarp\\_jeff.PDF](http://web.nps.navy.mil/~me/healey/papers/iarp_jeff.PDF).

### **THESIS DIRECTED:**

Melvin, J.E., "AUV Fault Detection Using Model-Based Observer Residuals," Master's Thesis and Naval Postgraduate School Technical Report, NPS-ME-98-004, June 1998.

**DoD KEY TECHNOLOGY AREA:** Other (Robotics, Autonomous Systems, Fault Detection)

**KEYWORDS:** Autonomous Systems, Robotics, Vehicles, Navigation

### **MODELING OF FIRE AND SMOKE PROPAGATION IN SHIPBOARD SPACES**

**Matthew D. Kelleher, Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** The objective of this proposed work is to model the propagation of fire and smoke in the shipboard environment. Specifically the effects of fire on the thermal environment of missiles in the launch systems of surface combatant ships has been modeled. Distributed lumped capacitance and thermal resistance models have been formulated to obtain time response behavior of a missile in a canister within a cell in the Concentric Canister Launcher (CCL) system. More detailed computational fluid dynamics models of the fire induced environment within these systems has also been used to determine the effects on the missile of fire in the vicinity of and within the missile magazines. Work has recently begun to investigate the modeling of smoke propagation in shipboard compartments and passageways. It is very important that an understanding of the propagation of fire and smoke in the various shipboard spaces be developed and that some means be developed to apply that understanding to incorporate survivability considerations in the design of future combatants and to the development of fire fighting procedures.

**SUMMARY:** A commercial code developed by CFD Research Corporation (CFDRC) has been used to model the effects of fire in various shipboard spaces. A model has been developed to predict the effects of a fire in an adjacent compartment on the environment in a missile magazine. The model has been used to predict the effects of a high temperature fire caused by burning missile propellant such as that experienced by the USS STARK (FFG-31) on the time and location of the critical cook-off temperatures of the missile's propellants.

**DoD KEY TECHNOLOGY AREA:** Modeling and Simulation

**KEYWORDS:** Fire Propagation, Ship Survivability, Damage Control, Missile Magazines

### **MODELING AND SIMULATION OF DAMAGE AND CRACKS IN PARTICULATE COMPOSITE MATERIALS: STUDY OF THICKNESS EFFECTS AND INITIAL CRACK SIZE**

**Young W. Kwon, Associate Professor**  
**Department of Mechanical Engineering**  
**Sponsors: Air Force Research Laboratory and Naval Postgraduate School**

**OBJECTIVE:** This was a continuing research project from past years during which a numerical modeling and simulation technique had been developed and evaluated against experimental results. The developed method was called a micro/macro approach. This year's effort was to investigate the effects of specimen thickness on the crack tip behavior including onset of crack propagation. A three-dimensional finite element analysis was conducted for the macrolevel analysis.



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**SUMMARY:** Damage saturation (i.e., the onset of crack propagation) occurred at the same applied strain level for both thick and thin specimens. For the thick specimens, the damage saturation was uniform more than 90 percent of the thickness. Thus, uniform crack propagation through the thickness was predicted and observed for thick specimens. The short crack had a long delay (about 100 percent larger applied strain) in damage initiation than the long crack, but the damage growth rate in the long crack was about 15 percent greater than the short crack. The slower damage growth in the short crack resulted in the higher maximum stress in the loading direction. At the onset of damage saturation, the longer crack had more damage concentration around the crack tip.

### PUBLICATIONS:

Kwon, Y.W. and Kim, C., "Micromechanical Model for Thermal Analysis of Particulate and Fibrous Composites," *Journal of Thermal Stresses*, Vol. 21, pp. 21-39, 1998.

Kwon, Y.W. and Baron, D.T., "Numerical Predictions of Progressive Damage Evolution in Particulate Composites," *Journal of Reinforced Plastics and Composites*, Vol. 17, No. 8, pp. 691-711, 1998.

Kwon, Y.W. and Liu, C.T., "Damage Growth in a Particulate Composite Under a High Strain Rate Loading," *Mechanics Research Communication*, Vol. 25, No. 3, pp. 329-336, 1998.

Kwon, Y.W., Lee, J.H., and Liu, C.T., "Study of Damage and Crack in Particulate Composites," *Composites, Part B: Engineering*, Vol. 29B, pp. 443-450, 1998.

Kwon, Y. W. and Liu, C. T., "Effects of Non-Uniform Particle Distributions on Damage Evolution in Pre-Cracked, Particulate Composite Specimens," *Polymers and Polymer Composites*, accepted for publication, 1998.

Liu, C.T. and Kwon, Y.W., "Numerical Modeling of Damage Initiation and Evolution Processes in a Particulate Composite Material," *Proceedings of the International Conference on Computational Engineering Science*, 1998.

Kwon, Y.W. and Liu, C.T., "Progressive Damage Around the Crack Tip in a Particulate Composite Made of Rubber-Like Matrix Material," *Proceeding of the Fifth International Conference on Composites Engineering*, Las Vegas, NV, July 1998.

Kwon, Y.W. and Liu, C.T., "Damage Evolution Near Crack Tips of Hard Particle Filled Rubber-Like Composites: Effects of Specimen Thickness and Crack Size," *Proceeding of the International Mechanical Engineering Congress and Exhibition*, November 1998.

### CONFERENCE PRESENTATIONS:

Liu, C.T. and Kwon, Y.W., "Numerical Modeling of Damage Initiation and Evolution Processes in a Particulate Composite Material," International Conference Computational Engineering Science, Atlanta, GA, October 1998.

Kwon, Y.W. and Liu, C.T., "Progressive Damage Around the Crack Tip in a Particulate Composite Made of Rubber-Like Matrix Material," Fifth International Conference on Composites Engineering, Las Vegas, NV, July 1998.

Kwon, Y.W. and Liu, C.T., "Damage Evolution Near Crack Tips of Hard Particle Filled Rubber-Like Composites: Effects of Specimen Thickness and Crack Size," International Mechanical Engineering Congress and Exhibition, Anaheim, CA, November 1998.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Particle Reinforced Composite, Solid Rocket Propellant, Damage and Crack, Modeling and Simulation, Thickness Effects

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## PROJECT SUMMARIES

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### DEVELOPMENT OF A ROBUST, HIGHER-ORDER SHELL ELEMENT WITH PRESSURE VARIATION THROUGH THE SHELL THICKNESS FOR DYSMAS PROGRAM

Young W. Kwon, Associate Professor  
Department of Mechanical Engineering  
Sponsor: Naval Surface Warfare Center

**OBJECTIVE:** This was a continuing research project from the previous year. This year's effort was to implement the plastic constitutive model including void effects into the shell element developed from the previous years.

**SUMMARY:** The shell element developed during the previous year was extended to include an elastoplastic constitutive model including void growth and nucleation. Gurson's void model was used. The shell element included both transverse shear and normal strains. It was also implemented into a transient analysis program using the central time integration technique. An algorithm for a stable solution with nonlinear deformation was developed. Furthermore, an hourglass control scheme was developed and applied to the shell element. Several test problems were solved for verification of the developed computer program.

#### **PUBLICATION:**

McMermott, P.M. and Kwon, Y.W., "Development of a Shell Element with Pressure Variation Through the Thickness-Part II," Naval Postgraduate School Technical Report, NPS-ME-98-005, September 1998.

**DoD KEY TECHNOLOGY AREAS:** Materials, Processes, and Structures, Modeling and Simulation

**KEYWORDS:** Finite Element Method, Higher-Order Shell Element, Constitutive Model for Void

### BIOMECHANICAL STUDY OF HUMAN BODY INJURY UNDER EXTREME LOADING

Young W. Kwon, Associate Professor  
Department of Mechanical Engineering  
Sponsor: Unfunded

**OBJECTIVE:** This was a continuing research project from a previous funded project. The effort was to model, simulate, and evaluate potential injury of the human body at various parts when subjected to an extreme loading such as mechanical impact and explosion.

**SUMMARY:** Three parts of the project were completed. The first study investigated the injury potential of the human head and neck of a soldier wearing a helmet that was impacted by a bullet. The focus was placed on the cervical spine injury. The second part examined the effectiveness of countermine boots against an AP mine. The study examined the protection of the boots from possible amputation of the lower leg caused by mine explosion. The last part studied the injury potential of a soldier in a military vehicle called HUMVEE when it rode on an explosive mine. The studies validated the modeling and results by comparing to available experimental results. In addition, the study investigated several possible scenarios under various conditions to predict injury potentials.

#### **PUBLICATIONS:**

Kwon, Y.W. and King, Q.M., "Biomechanical Study of Ballistic Impact on Helmets: Injury of Head and Neck," *Recent Advances in Solids and Structures*, ASME PVP-Vol. 381, pp. 55-62, 1998.

Kwon, Y.W. and Muschek, R.C., "Study of Effectiveness of Countermine Boots," *Recent Advances in Solids and Structures*, ASME PVP-Vol. 381, pp. 63-70, 1998.

## PROJECT SUMMARIES

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### CONFERENCE PRESENTATIONS:

Kwon, Y.W. and King, Q.M., “Biomechanical Study of Ballistic Impact on Helmets: Injury of Head and Neck,” 1998 ASME International Mechanical Engineering Congress and Exposition, Anaheim, CA, November 1998.

Kwon, Y.W. and Muschek, R.C., “Study of Effectiveness of Countermine Boots,” 1998 ASME International Mechanical Engineering Congress and Exposition, Anaheim, CA, November 1998.

### THESES DIRECTED:

King, Q.M., “Investigation of Biomechanical Response due to Fragment Impact on Ballistic Protective Helmet,” Master’s Thesis, Naval Postgraduate School, March 1998.

Muschek, R.C., “Evaluation of the Mechanical Properties and Effectiveness of Countermine Boots,” Master’s Thesis, Naval Postgraduate School, March 1998.

Lee, K.-S., “Biomechanical Response of the Human Body Inside a Military Vehicle Exposed to Mine Explosion,” Master’s Thesis, Naval Postgraduate School, December 1998.

**DoD KEY TECHNOLOGY AREAS:** Biomedical, Modeling and Simulation

**KEYWORDS:** Biomechanics, Injury of Human Body, Finite Element Model

## PROCESSING GRAIN BOUNDARIES AND SUPERPLASTICITY IN ALUMINUM

**Terry R. McNelley, Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Unfunded**

**OBJECTIVE:** The goal of this program is to determine the mechanisms of grain boundary development during deformation processing, and the mechanisms by which deformation microstructures may transform to a fine-grained superplastic state.

**SUMMARY:** Recently developed computer-aided electron microscopy diffraction analysis methods have been applied to the investigation of the mechanisms of grain boundary development during deformation processing and annealing of pure aluminum and several superplastic aluminum alloys. Materials have been examined following various thermomechanical processing schedules and deformation histories. A program of investigation into pure Aluminum processed by equi-channel angular (ECA) pressing has been initiated. Research has continued on Aluminum alloys 5083, 7475 and laboratory-processed 2519, which are all observed to transform to a refined, superplastic microstructure via a primary (discontinuous) recrystallization reaction involving the formation and migration of high-angle grain boundaries. However, Supral 2004, Al-10Mg-0.1Zr and Al-5Ca-5Zn materials transform by a continuous process. These different transformation processes may be distinguished by distinctly different grain boundary misorientation distributions. Primary recrystallization produces a random distribution similar to that predicted by Mackenzie for randomly oriented cubes and the resultant superplastic response is often relatively limited. The continuous reaction results in a bi-modal misorientation distribution, with many moderately misoriented boundaries of misorientation near 10 degrees, and a much more highly superplastic response.

### PUBLICATIONS:

Pérez-Prado, M.T., McNelley, T.R., Ruano, O.A., and González-Doncel, G., “Microtexture Evolution During Annealing and Superplastic Deformation,” *Metallurgical and Materials Transactions A*, 29A, pp. 485-492, 1998.

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## PROJECT SUMMARIES

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Pérez-Prado M.T., McMahon, M.E., and McNelley, T.R., “A Model for Texture-Related Grain Boundary Misorientations in a Superplastic Aluminum Alloy,” *Modeling the Mechanical Response of Structural Materials*, E.M. Taleff and R.K. Mahidhara, (eds.), pp. 181-190, TMS, Warrendale, PA, 1998.

McNelley, T.R. and McMahon, M.E., “Recrystallization and Superplasticity in Aluminum Alloys,” *Superplasticity and Superplastic Forming*, A. K. Ghosh and T. R. Bieler, (eds.), pp. 75-87, TMS, Warrendale, PA, 1998.

McNelley, T.R., Pérez-Prado, M.T., and McMahon, M.E., “Grain Boundary Evolution During Elevated Temperature Deformation of Two Superplastic Aluminum Alloys,” *Hot Deformation of Aluminum Alloys II*, T.R. Bieler, L.A. Lalli, and S.R. MacEwen, (eds.), pp. 229-242, TMS, Warrendale, PA, 1998.

McNelley, T.R., McMahon, M.E., and Pérez-Prado, M.T., “Grain Boundary Evolution and Continuous Recrystallization of a Superplastic Al-Cr-Zr Alloy,” *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, in press.

Pérez-Prado, M.T. and McNelley, T.R., “Dependence of the Grain Boundary Misorientation Distribution in Supral 2004 on the Plane of Observation,” *Scripta Materialia*, in review.

### CONFERENCE PRESENTATIONS:

McNelley, T.R. and McMahon, M.E., “Recrystallization and Superplasticity in Aluminum Alloys,” Symposium on Superplasticity and Superplastic Forming, 1998 Annual Meeting of the Metals, Minerals, and Materials Society (TMS), San Antonio, TX, 16 February 1998.

Pérez-Prado, M.T., McMahon, M.E., and McNelley, T.R., “A Model for Texture-Related Grain Boundary Misorientations in a Superplastic Aluminum Alloy,” Symposium on Modeling the Mechanical Response of Structural Materials, 1998 Annual Meeting of the Metals, Minerals, and Materials Society (TMS), San Antonio, TX, 18 February 1998.

McNelley, T.R., McMahon, M.E., and Pérez-Prado, M.T., “Grain Boundary Evolution During Processing and Deformation of Superplastic Aluminum Alloys,” Symposium on Superplasticity and Superplastic Forming, 35<sup>th</sup> Annual Technical Meeting of the Society of Engineering Science, Washington State University, Pullman, WA, 28 September 1998.

McNelley, T.R., McMahon, M.E., and Pérez-Prado, M.T., “Processing, Grain Boundaries, and Superplastic Deformation of Aluminum,” Symposium on Hot Deformation of Aluminum Alloys, 1998 Annual Fall Meeting of the Metals, Minerals, and Materials Society (TMS), Chicago, IL, 13 October 1998.

McNelley, T.R., “Deformation Processing and Grain Boundaries in a Superplastic Al-Cu-Zr Alloy,” Discussion Meeting on Deformation Processing of Metals, the Royal Society, London, United Kingdom, 22 October 1998.

### THESIS DIRECTED:

Terhune, Shannon D., “An Electron Backscatter Diffraction Analysis of the Microstructure of Pure Aluminum Processed by Equal-Channel Angular Pressing,” Master’s Thesis, Naval Postgraduate School, December 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Aluminum, Superplasticity, Recrystallization, Grain Boundaries, Thermomechanical Processing

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## PROJECT SUMMARIES

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### **A KNOWLEDGE-BASED APPROACH TO FRACTURE TOUGHNESS IMPROVEMENT VIA PROCESSING FOR PARTICULATE-REINFORCED ALUMINUM METAL MATRIX COMPOSITES**

**Terry R. McNelley, Professor**

**Department of Mechanical Engineering**

**Sponsor: U.S. Army Research Office/Army Research Laboratory**

**OBJECTIVE:** The goal of this program is obtain improved combinations of strength, ductility, and toughness in Al-based metal-matrix composite materials by thermomechanical processing.

**SUMMARY:** Discontinuously reinforced Al matrix composite materials have many attractive properties but lack adequate ductility and toughness for many applications. Dramatic improvements in composite ductility have been attained in extruded 6061 Al-Al<sub>2</sub>O<sub>3</sub> composites processed using methods designed to redistribute the Al<sub>2</sub>O<sub>3</sub> particles as well as achieve a fully recrystallized matrix grain structure via particle-stimulated nucleation of recrystallization. Further improvements in ductility have been obtained with use of controlled heat treatments on processed material. The influence of deformation temperature on redistribution of particles during processing has been investigated by controlled deformation of samples in a channel die. Fracture toughness improvements in extruded powder metallurgy 6092 Al-SiC material have been demonstrated and strength-toughness combinations equivalent to those of the unreinforced matrix alloy have been attained.

#### **PUBLICATION:**

Dutta, I., Quiles, F.N., McNelley, T.R., and Nagarajan, R., "Optimization of the Strength-Fracture Toughness Relation in Particulate Reinforced Aluminum Composites via Control of Matrix Microstructure," *Metallurgical and Materials Transactions A*, 29A, pp. 2433-2446, 1998.

#### **CONFERENCE PRESENTATION:**

McNelley, T.R. and Dutta, I., "Matrix Effects on Deformation and Fracture of DRA Composites Symposium on Discontinuously Reinforced Composites: Present and Future," 1998 Annual Fall Meeting of the Metals, Minerals, and Materials Society (TMS), Chicago, IL, 13 October 1998.

#### **THESIS DIRECTED:**

Markovich, John J., "Evaluation of Microstructure of a 6092 Al - 17.5 vol. pct. SiC<sub>p</sub> Particle Reinforced Composite Using Electron Backscatter Pattern (EBSP) Analysis Methods," Master's Thesis, Naval Postgraduate School, March 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Metal-Matrix Composites, Processing, Particle Distribution, Fracture Toughness

### **CONDITION-BASED MAINTENANCE FOR DIESEL ENGINES**

**Knox T. Millsaps, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** To develop a method for determining cylinder firing pressure based on the instantaneous shaft speed. This technique is used to identify and localize faults in internal combustion engines.

**SUMMARY:** A torsional, dynamic engine model for a 3-cylinder, 2-stroke Diesel engine was developed and calibrated. Measurements of near instantaneous shaft speed at both ends of the engine were made on a real engine for a wide range of applied torques and speeds. The model is capable of predicting shaft speed variations. An inverse method, for determination

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of gas torques based of these speed fluctuations was developed and verified. Finally a dynamic finite element method was developed to predict the angular motion of the crankshaft. This method was proven to be more than 100 times more efficient than the time-marching “shooting” method that was previously used.

### PUBLICATIONS:

Millsaps, K.T., Swanson, W.J., Bell, J.A., and Hudson, J., “Development and Calibration of a High Fidelity Torsional Engine Model for a 3-Cylinder Diesel Engine,” submitted to SAE, 1998.

Millsaps, K.T. and Swanson, W.J., “Determination of Diesel Cylinder Gas Torques from Speed Fluctuation High-Fidelity Crankshaft Torsional Model,” submitted to SAE, 1998.

Swanson, W.J. and Millsaps, K.T., “An Efficient Method for the Determination of Periodic Torsional Motion of a Crankshaft Using Dynamic Finite Elements,” submitted to SAE 1998.

### THESIS DIRECTED:

Swanson, W.J., “Determination of Diesel Engine Cylinder Gas Torques from Speed Fluctuation with a High-Fidelity Crankshaft Torsional Model,” Master’s Thesis, Naval Postgraduate School, December 1998.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Sensors

**KEYWORDS:** Condition Based Maintenance, Diesel Engines, Cylinder Firing Pressure, Torsional Vibrations, Finite Element Methods

### ENHANCED SUPPRESSION EDUCTOR FOR THE LOW OBSERVABLE MULTI-FUNCTION STACK (LMS) ADVANCED TECHNOLOGY DEMONSTRATOR (ATD)

**Knox T. Millsaps, Associate Professor**

**Department of Mechanical Engineering**

**Garth V. Hobson, Associate Professor**

**Department of Aeronautics and Astronautics**

**Sponsors: Naval Surface Warfare Center-Carderock Division**

**Naval Sea Systems Command, and Office of Naval Research**

**OBJECTIVE:** To develop and verify an enhanced mixing performance eductor design for the Low Observable Multi-Function Stack (LMS) Advanced Technology Demonstrator (ATD). Also to provide consulting services as necessary to the ATD program.

**SUMMARY:** A 1-D design code for preliminary design of suppressing eductors was developed and used to obtain the preliminary scaling for the LMS enhanced mixing eductor. A sub-scale, cold-flow facility was designed, constructed and is operational. It was used to verify two design concepts developed at NPS for the LMS program. Specifically, the secondary induction and outlet flow profiles were measured for both parallel slot and radial slot enhanced mixing eductor designs. The performance was within 5% of that predicted, based on a 1-D design code. Additional support to the ATD program was supplied. Specifically, the instrumentation package for measuring the baseline engine exhaust flow was designed and the data from the tests were analyzed. Concepts for installing the suppressor were proposed and analyzed.

### OTHER:

Millsaps, K.T. and Hobson, G.V., “Preliminary Design Report for the NPS LMS Eductor,” 1 March 1998.

Millsaps, K.T., “Title Omitted,” Classified Report to NSWC-Carderock, June 1998.

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### THESIS DIRECTED:

Otis, R., "Modeling and Design of an Enhanced Warship Signature Suppression Eductor," Master's Thesis, Naval Postgraduate School, March 1998.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Surface Vehicles)

**KEYWORDS:** Infrared Signature Suppression, Ejectors, Eductors, Plume Temperature Reduction, Gas Turbine Exhausts

### DEVELOPMENT OF MATLAB-BASED PROGRESSIVE FLOODING DYNAMICS WITH A GRAPHICS INTERFACE

**Fotis A. Papoulias, Associate Professor**  
**Charles N. Calvano, Associate Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** The objective of this project is to utilizing modeling and simulation methods based on MATLAB and SIMULINK in order to predict the fundamental dynamics of ship progressive flooding and develop the means to assess various flooding scenarios and countermeasures in a systematic way.

**SUMMARY:** The computational power of MATLAB can be combined with the ease of implementation of SIMULINK in order to set the fundamentals for a user friendly, modular, and expandable ship progressive flooding design tool. This approach has the added advantage of evaluating the degree of accuracy versus difficulty of implementation during each program upgrade. Extension to arbitrary ship compartment geometries is feasible through the use of look-up tables. Since SIMULINK lacks the internal description of piping properties and dewatering pump characteristics, it is necessary to build a collection of standard blocks which will contain a mathematical description of these properties. This can become a standard library that will be accessible to the end user from within the SIMULINK graphical environment. The standard pump characteristics library must be as identical as possible to the library that has been developed for NAVSEA and has been incorporated in the simulation package SIMSMART. The complete package of MATLAB functions and SIMULINK block diagrams will be accessible from a user friendly Graphical User Interface with the appropriate callback functions. In this way, the complete system will be event-driven and will be used in order to establish or assess the effectiveness of various countermeasure actions.

### THESIS DIRECTED:

Wright, Russell A., "Improved Computer Modeling of Ship Progressive Flooding as a Design Tool," Naval Postgraduate School, September 1998.

**DoD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Ship Motions, Stability, Flooding, Progressive Flooding

### DEVELOPMENT OF A NEW VORTEX-DECAY MODEL IN THE ATMOSPHERE

**Turgut Sarpkaya, Distinguished Professor**  
**Department of Mechanical Engineering**  
**Sponsor: National Aeronautics and Space Administration-Langley**

**OBJECTIVE:** The purpose of this continuing investigation is: (1) to develop a new vortex decay model for the prediction of the descent of aircraft trailing vortices subjected to realistic environmental conditions (stratification, turbulence, cross



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wind, headwind, shear effects, and ground effect) and (2) to apply the model to field data obtained with Lidar in Memphis and Dallas–Fort Worth airports.

**SUMMARY:** A robust and relatively simple physics-based vortex decay model has been devised. It does not violate any hydrodynamical principles, has only one model constant, uses the turbulence eddy dissipation rate in conjunction with a theoretical model (as verified by experiments and numerical simulations), and it requires no cumbersome algorithms to account for the ground effects. Acquisition of better and more detailed field data (vortex velocities and positions; wind, shear, and their gradients; better temperature, humidity, and eddy dissipation profiles), the quantification of the consequences of unstable stratification, and the optimization of the new model parameters constitute the essence of this continuing research of vital international importance.

### PUBLICATIONS:

Feyedelem, M.S. and Sarpkaya, T., “Free- and Near-Free-Surface Swirling Turbulent Jets,” *American Institute of Aeronautics and Astronautics (AIAA) Journal*, Vol. 36, No. 3, pp. 359-364, March 1998.

Sarpkaya, T., “Decay of Wake Vortices of Large Aircraft,” *American Institute of Aeronautics and Astronautics (AIAA) Journal*, Vol. 36, No. 9, pp. 1671-1679, September 1998.

### CONFERENCE PRESENTATIONS:

Sarpkaya, T., “Decay of Wake Vortices of Large Aircraft,” American Institute of Aeronautics and Astronautics Aerospace Sciences Meeting, Reno, NV, January 1998.

Sarpkaya, T., “A New Model for Vortex Decay in the Atmosphere,” AIAA Paper No: 99-0761, (to be presented at the American Institute of Aeronautics and Astronautics Aerospace Sciences Meeting, Reno, NV, January 1999).

### THESIS DIRECTED:

Murat, M., “Aircraft Trailing Vortices: Greene’s Model Versus Field Data,” Master’s Thesis, Naval Postgraduate School, June 1998.

**DoD KEY TECHNOLOGY AREA:** Air Vehicles

**KEYWORDS:** Trailing Vortices, Aircraft Wakes, Wake Hazard

## A UNIVERSAL FORCE MODEL FOR BLUFF BODIES IN UNSTEADY FLOW

**Turgut Sarpkaya, Distinguished Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Office of Naval Research**

**OBJECTIVE:** The purpose of this investigation is to carry out combined analytical, numerical, physical, and thought experiments to devise a physics-based model for the prediction of flow-induced unsteady forces on bluff bodies immersed in time-dependent flows. The new model, based on a sounder scientific rationale, is expected to modify the well-known Morison equation and offer greater universality and higher engineering reliability, particularly in the so-called drag-inertia regime.

**SUMMARY:** Over 3,000 digital force-time-data files have been evaluated during the course of the investigation in order to evaluate the residue for each combination of the Keulegan-Carpenter number  $K_c$ , Frequency parameter  $b$ , the Reynolds number  $Re$ , and the relative roughness  $k_s/D$ . It has been shown that the viscous drag force and the inviscid inertia force do not operate independently and it is not possible to divide the measured time-dependent force into an inviscid inertial force

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## PROJECT SUMMARIES

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and a viscous drag force. The modification proposed herein to the existing Morison equation through the addition of a third term offers greater universality and higher engineering reliability, particularly in the so-called drag-inertia regime.

### PUBLICATION:

Sarpkaya, T., "Resistance in Unsteady Flow: Search for a Physics-Based Model," *Proceedings of the 22nd Symposium on Naval Hydrodynamics*, Vol. 1, pp. 312-323, National Academy Press, Washington, DC, 1998.

### CONFERENCE PRESENTATION:

Sarpkaya, T., "Resistance in Unsteady Flow: Search for a Physics-Based Model," 22nd Symposium on Naval Hydrodynamics, Washington, DC, 9-14 August 1998.

**DoD KEY TECHNOLOGY AREA:** Modeling and Simulation

**KEYWORDS:** Bluff Body, Resistance, Unsteady Flows, Vorticity

## SPRAY FORMATION AT THE FREE SURFACE OF LIQUID WALL JETS

**Turgut Sarpkaya, Distinguished Professor**

**Department of Mechanical Engineering**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** This continuing basic research is an experimental investigation of the ligament and drop formation at the free surface of liquid wall jets, flowing over smooth and sand-roughened plates towards the understanding of the physics of droplet formation, in general, and of the spray formation on bow-sheets, in particular.

**SUMMARY:** Measurements were made with several high-speed imagers, a pulsating laser, and a Digital Particle Image Velocimeter (DPIV) system and analyzed through the use of appropriate software. The wall-jet Reynolds number ranged from  $2.4 \times 10^4$  to  $4 \times 10^4$ , the Froude number from 15 to 30, and the Weber number from 1,500 to 3,000. The characteristics of the ligament forest and droplets were determined from the digitized images.

### PUBLICATIONS:

Merrill, C.F. and Sarpkaya, T., "Spray Formation at the Free Surface of a Wall Jet," *American Institute of Aeronautics and Astronautics (AIAA) Paper*, No. 98-0442, 1998.

Sarpkaya, T. and Merrill, C., "Spray Formation at the Free Surface of Rough-Wall Jets," *Proceedings of the Third International Conference on Multiphase Flow, ICMF'98*, Paper No. 105, pp. 1-8, Lyon, France, 8-12 June 1998.

Sarpkaya, T. and Merrill, G., "Spray Formation at the Free Surface of Liquid Wall Jets," *Proceedings of the Symposium on 22nd Naval Hydrodynamics*, pp. 145-154, 9-14 August 1998.

### CONFERENCE PRESENTATIONS:

Merrill, C.F. and Sarpkaya, T., "Spray Formation at the Free Surface of a Wall Jet," American Institute of Aeronautics and Astronautics Aerospace Sciences Meeting, Reno, NV, January 1998.

Sarpkaya, T. and Merrill, C., "Spray Formation at the Free Surface of Rough Wall Jets," Third International Conference on Multiphase Flow, ICMF'98, Lyon, France, 8-12 June 1998.

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Sarpkaya, T. and Merrill, G., "Spray Formation at the Free Surface of Liquid Wall Jets," 22nd Symposium on Naval Hydrodynamics, Washington, DC, 9-14 August 1998.

### DISSERTATION DIRECTED:

Merrill, C.F., "Spray Generation from Liquid Wall Jets Over Smooth and Rough Surfaces," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1998.

**DoD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Hydrodynamics, Drop Formation, Spray

### VORTEX BREAKDOWN IN TURBULENT SWIRLING FLOWS

**Turgut Sarpkaya, Distinguished Professor**

**Department of Mechanical Engineering**

**Sponsors: National Science Foundation and Naval Postgraduate School**

**OBJECTIVE:** Trailing vortices, swirling flows in pipes, vortical flows above sweptback wings at large angles-of-attack, flows in closed containers with a rotating lid, and columnar vortices in atmosphere may experience breakdown: *The transformation of a slender vortex into three-dimensional forms*. Where, how, and under what circumstances does this transformation occur in *viscous* vortical flows constitute the essence of the breakdown problem.

**SUMMARY:** The mean velocities and turbulence intensities were measured in forward-scattering mode with a three-component Laser Doppler Anemometer. The results refute the conjectures that the circumstances of breakdown are insensitive to the Reynolds number and the local turbulence properties. These two factors have a strong influence on the evolution of the flow. Of all the known forms, the spiral emerges as the most fundamental breakdown form. All other forms may be regarded as transient states affected by various types of instabilities. At very high Reynolds numbers the breakdown acquires forms and characteristics never seen before: Extremely high rates of revolution, onset of core-bifurcation or core-trifurcation, intense nonisotropic turbulence, and a conical shape.

### PUBLICATION:

Sarpkaya, T. and Novak, F., "Turbulent Vortex Breakdown: Experiments in Tubes at High Reynolds Numbers," Book Chapter in *Slender Vortices*, pp. 287-296, E. Krause and K. Gersten, (eds.), Kluwer Press, Dordrecht, The Netherlands, 1998.

### CONFERENCE PRESENTATION:

Novak, F. and Sarpkaya, T., "Turbulent Vortex Breakdown at High Reynolds Numbers," Aerospace Sciences Meeting of the American Institute of Aeronautics and Astronautics, Reno, NV, to be presented, January 1999.

### DISSERTATION DIRECTED:

Novak, F., "An Experimental Investigation of Vortex Breakdown in Tubes at High Reynolds Numbers," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1998.

**DoD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Air Vehicles

**KEYWORDS:** Vortex Breakdown, Vorticity, Swirling Flow

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### SHOCK AND VIBRATION ANALYSIS IN SUPPORT OF DDG-51 CLASS SHOCK FOLLOW-ON ACTIONS

Young S. Shin, Professor

Department of Mechanical Engineering

Sponsors: Naval Sea Systems Command and Naval Postgraduate School

**OBJECTIVE:** To perform shock and vibration analysis in support of DDG-51 Class shock follow-on actions including DDG-51 Flight IIA ship shock analysis to predict dynamic responses of ship system and subsystem structures to underwater explosions.

**SUMMARY:** This task is a part of team project consisting of NAVSEA, NSWC, Electric Boat, Weindlinger Associates, Gibbs and Cox, and NPS. The FY98-task was to conduct surface ship shock modeling and simulation of DDG-53. The task includes investigating whether the ship shock modeling and simulation can predict the dynamic transient responses of ship system and subsystem structures accurately. The analysis takes into account of the effects of the fluid-ship structure interaction and cavitation effects on a surface ship model (DDG-53) due to a large scale underwater explosion.

#### PUBLICATION:

Shin, Y.S. and Santiago, L.D., "Surface Ship Shock Modeling and Simulation: 2D Analysis," *Journal of Shock and Vibration*, Vol. 5, No. 2, 1998.

#### CONFERENCE PRESENTATIONS:

Shin, Y.S., Wood, S.L., and Park, S.Y., "Ship Shock Simulation of DDG53 John Paul Jones," 69<sup>th</sup> Shock and Vibration Symposium, Minneapolis/St. Paul, MN, 12-16 October 1998.

Shin, Y.S. and Wood, S.L., "Cavitation Effects to Ship-Like-Box Structure for Underwater Explosion," 69<sup>th</sup> Shock and Vibration Symposium, Minneapolis/St. Paul, MN, 12-16 October 1998.

#### THESES DIRECTED:

Wood, S.L., "Cavitation Effects on a Ship-Like Box Structure Subjected to an Underwater Explosion," Master's Thesis, Naval Postgraduate School, September 1998.

Beiter, K.A., "The Effect of Stiffener Smearing in a Ship-Like-box Structure Subjected to an Underwater Explosion," Master's Thesis, Naval Postgraduate School, June 1998.

**DoD KEY TECHNOLOGY AREAS:** Surface/Under Surface Vehicles-Ships and Watercraft, Modeling and Simulation

**KEYWORDS:** Surface Ship, Underwater Explosion, Cavitation, Fluid-Structure Interaction

### SURVIVABILITY OF SHIPBOARD PERSONNEL SUBJECTED TO HIGH AMPLITUDE, LOW FREQUENCY SHOCK INDUCED BY UNDERWATER EXPLOSION

Young S. Shin, Professor

Department of Mechanical Engineering

Sponsor: Unfunded

**OBJECTIVE:** The goal is to develop a method for estimating crew survivability to a given underwater explosion event. Biodynamic simulations of human response to shock induced deck excitation were performed for both male and female subjects using the Articulated Total Body (ATB) program. Subsequently, the results were used to estimate the biodynamic

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response and injury potentials for human males and females in various positions in a vessel to an underwater explosion event.

**SUMMARY:** The Articulated Total Body (ATB) modeling approach was used to model the motion of a human (or test dummy such as the Hybrid III) in response to ship shock. The investigation was conducted to simulate the response such as the gross motion, the contact forces between body parts and the surrounding environment, the torque within the body's joints, and the relative accelerations of the body parts (head acceleration with respect to the upper torso, for example). In addition, the description of the injuries investigated and their associated injury tolerances were studied.

### **PUBLICATIONS:**

Oglesby, D.B. and Shin, Y.S., "Simulation of Human Male and Female Biodynamic Response to UNDEX Events," *Proceedings of the 69<sup>th</sup> Shock and Vibration Symposium*, CD-ROM, Minneapolis/St. Paul, MN, 12-16 1998.

Oglesby, D.B. and Shin, Y.S., "ATB Program and Its Applications to Biodynamic Response Simulation of Underwater Explosion Events," Naval Postgraduate School Technical Report, NPS-ME-98-002, March 1998.

### **THESIS DIRECTED:**

Oglesby, D.B., "Human Male and Female Biodynamic Response to Underwater Explosion Events," Master's and Engineers Thesis, Naval Postgraduate School, Monterey, CA, March 1998.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Underwater Explosion, Human Survivability, Biodynamic Response